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THE FILTER FOR HORN ANTENNA MULTIFREQUENCY DATA PROCESSING

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ABSTRACT

The transceiver horn antenna used in multifrequency microwave measurements for probing the structure under the test and receiving reflected power has two reference discontinuities. This causes obtained reflectivity dependency to be a superposition of two similar echoing characteristics, so that clear discerning reflectivity signal peaks and estimating their parameters is impossible in the most part of uniqueness range of Fourier transform, which is used for viewing the dependency in spatial area. The Filter for Horn Antenna Multifrequency Data Processing is designed for extracting single echoing characteristic from said dependency. This allows productive using almost all the uniqueness range provided that in the far-field region the reflectivity ratio of reference discontinuities and electric length of the horn do not depend on distance to structure under the test.

INTRODUCTION

The multifrequency reflectometers [1] implement the principle of synthesising radio pulse envelope [2] using data of reflectivity module measurements carried out in free space on a discrete frequency grid with the presence of reference discontinuity. Reflectivity is obtained as ratio of incident and reflected wave power, which is respectively irradiated and gathered by the transceiver antenna serving also as reference discontinuity (-ies). Complex-valued spatial echoing characteristic is obtained by inverse Fourier transform of measured frequency response.

GROUNDS FOR DEVELOPING THE FILTER

Practical usage of horn antennas in multifrequency reflectometer looks more preferable in comparison with simpler antennas like the open-ended waveguide (OEW), especially when remote testing is necessary (in industrial conditions, for example) because of their high gain (of about 25 dB). However, analysis of reflectivity dependencies derived with horn antennas in their primal view leaves unused the greater part of distance range of uniqueness of Fourier transform. The main difficulty is that direct measurement data represents a superposition of echoing characteristics corresponding to cross-correlation functions (CCFs) of reflectivity of structure under the test with that of throat and aperture of the horn. Thus for structure with electric width exceeding the electric length of the horn the clear interpreting of synthesised signal peaks is impossible. Removing

one of the characteristics (by some method) would allow using practically all the range of a uniqueness of measurements, only limiting the aperture-structure distance by structure's electric width.

MATHEMATICAL DESCRIPTION

We have researched the simplest of possible processings (further – horn antenna data filter) extracting a unique echoing characteristic. It is built using the following statements. The echoing characteristic $F(\omega)$ obtained with horn antenna is a superposition of three functions: $F_1(\omega) + F_2(\omega) + F_3(\omega)$ (typical look is shown on fig. 1a). The first of them corresponds to correlation of structure's echoing characteristic with that of the first reference discontinuity (horn's throat, for example), the second – similarly with the second (accordingly, aperture). The third is attributed all the rest, in particular auto-correlation functions of discontinuities, CCF of reference discontinuities and other (possibly unexpected) components. Further, in spatial domain it is possible to consider the function $F_2(z)$ as $kF_1(z + \Delta z)$, where Δz is the shift along the measurement axis (equal to electric length of the horn), k is a complex multiplier taking into account the amplitude ratio and phase difference of reflection signals corresponding to CCF structure-aperture and structure-horn's throat. It is supposed that $k = const$ in the far-field region. Specified parameters are subject for experimental determination, because of their individuality for each horn in concrete frequency band and measurement installation calibrations being in use.
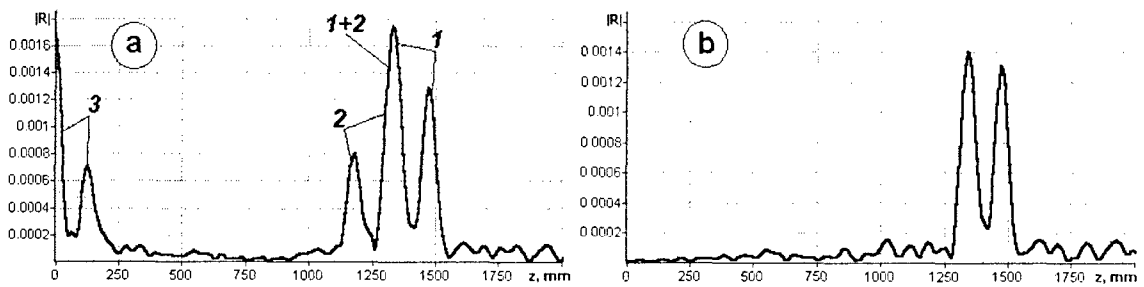

Fig 1: a – typical view of raw synthesised spatial signal for single-layer structure (1, 2, 3 – components of F_1, F_2, F_3 respectively, 1+2 – a case of superposition of F_1 and F_2); b – single echoing characteristic F_1, derived with the filter

Thus, in frequency area $F_2(\omega) = kF_1(\omega)\exp(j\omega \cdot \Delta t)$ where $\Delta t = \dfrac{2\Delta z}{c}$, c is the speed of light in vacuum, and 2 is the multiplier taking into account forward wave propagation up to the structure and backwards after reflection. To use this relation we delete the component F_3 in spatial area (in working realisation of the filter it is done by applying trapezoidal window with transition width, which equals to 0.5% of the uniqueness range, but is not less than 3 discrete spatial samples). Now in frequency area the echoing characteristic appears as $(1 + k \cdot \exp(j\omega \cdot \Delta t)) \cdot F_1(\omega)$, so the desired echoing characteristic may be obtained by dividing by the expression $1 + k \cdot \exp(j\omega \cdot \Delta t)$. Treating the result of division with Fourier transform, we gain the unique spatial echoing characteristic (fig. 1b).

In real conditions the most of assertions, on which the filter is based, are disturbed a little by random factors: unreproducibility of measurements, dispersion in experimentally determined filter parameters and their light nonconstancy conditioned by properties of and distance to structure under the test. Some of them may be compensated, for example, non-linear distortions and modulation of frequency response, other may not, for example, inexact concurrence of reflection signal shapes and levels for horn's aperture and throat causing either under- or over- or improper compensation of F_2. These effects may be considered as additional component F_4, which cannot be deleted by spatial window for F_3 or in other known ways. Dividing F_4 by $1 + k \cdot \exp(j\omega \cdot \Delta t)$ produces in a spatial domain the characteristics looking as $k^i F_4(z + i\Delta z)$, where $i = 1,2,3...$. Thus any uncompensated parasitic peak will give a series of peaks with the increasing (on $|k| > 1$) or decreasing (on $|k| < 1$) amplitude. So limiting $|k|$ by value close to one (for example 0.9) and extracting the greater of two echoing characteristics and also using the horn with as possible lower $|k|$ is necessary for the exception of "spawning" the parasitic components. Ideally, as well as in the case of OEW, absence of the second reference discontinuity makes the filtering unnecessary.

APPLICABILITY OF THE FILTER

Considered filter takes plenty of computational resources (it thrice uses the Fourier transform – first before applying spatial window, further returning to frequency area with subsequent dividing by $1 + k \cdot \exp(j\omega \cdot \Delta t)$, and at last obtaining the final spatial echoing characteristic). Nevertheless, this is not a serious problem for modern computer technology – the most part of the computer time is still spent on the obtained characteristics visualisation, so real-time measurements are anyway possible.

The results of applying the filter to actual reflectivity data give the basis for recommending its usage in reflectometers with a horn probe. For example, the measurements in 8-12.5 GHz range with the purpose of determining the dielectric constant (ε) for single-layer structures showed that the variation of filter parameters (separately) by ± 6 mm for Δz (at the wave length of 30 mm!), ± 0.1 for $|k|$, and ± 0.3 rad for $\arg(k)$ results in ε estimation deviation not greater than 0.11 for ε of about 3. The actual deviation of Δz, $|k|$ and $\arg(k)$ at different distances to the structure in far-field region measurements makes correspondingly ± 0.7 mm, ± 0.02, ± 0.07 rad, that results in the ε estimation error imported by the filter not greater than 0.02. It must be marked that the most preferable is applying the filter with the antenna of such a construction, which minimises $|k|$ maintaining its independence from the distance.

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